



**US Army Corps
of Engineers**

Construction Engineering
Research Laboratory

USACERL TECHNICAL REPORT P-90/14

July 1990

Knowledge-Based Techniques for RPMA Decisions

AD-A226 176

Employing Expert System Technologies to Real Property Management Decisionmaking

by

Sandra F. Kappes

Simon S. Kim

Patrick J. Tanner

Roddy J. Williams

Louis F. Cohn

The U.S. Army has an enormous real property inventory, valued (in 1988) at \$175 billion. The management of Real Property Maintenance Activities (RPMA) in the Army is a challenging and complex task. This report describes a study that reviewed U.S. Army RPMA to identify specific management areas that could be improved by use of knowledge-based programming techniques.

Two programs were selected to determine the feasibility of employing knowledge-based expert systems to assist in RPMA decisionmaking. The first system, outlined on the conceptual level, would automate the processes for prioritizing projects at the installation and Major Command levels. The second system models an expert system that would assist the Directorate of Engineering and Housing (DEH), Engineering Plans and Services (EP&S) division in scheduling design projects.

DTIC
ELECTED
SEP 04 1990
S_{cB}**D**

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official indorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED

DO NOT RETURN IT TO THE ORIGINATOR

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	July 1990	Final	
4. TITLE AND SUBTITLE			5. FUNDING NUMBERS
Employing Expert System Technologies to Real Property Management Decisionmaking			PR AT23 TASK SB WU EM9
6. AUTHOR(S)			
Sandra F. Kappes, Simon S. Kim, Patrick J. Tanner, Roddy J. Williams, and Louis F. Cohn			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Army Construction Engineering Research Laboratory (USACERL) 2902 Newmark Drive, PO Box 4005 Champaign, IL 61824-4005			TR P-90/14
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
HQUSACE 20 Massachusetts Avenue, NW. Washington, DC 20314-1000			
11. SUPPLEMENTARY NOTES			
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161			
12a. DISTRIBUTION/AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE	
Approved for public release; distribution is unlimited.			
13. ABSTRACT (Maximum 200 words)			
The U.S. Army has an enormous real property inventory, valued (in 1988) at \$175 billion. The management of Real Property Maintenance Activities (RPMA) in the Army is a challenging and complex task. This report describes a study that reviewed U.S. Army RPMA to identify specific management areas that could be improved by use of knowledge-based programming techniques.			
14. SUBJECT TERMS			15. NUMBER OF PAGES
Real Property Management Activities expert systems decision making			40
16. PRICE CODE			
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

FOREWORD

This study was performed for Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A161102AT23, "Basic Research in Military Construction," Work Unit SB-EM9, "Knowledge-Based Techniques for RPMA Decisions."

This research was performed by the Facility Systems Division (FS) of USACERL. Special acknowledgement is given to Mr. Donald Herby, Chief, Budget Section, FORSCOM Engineers, Fort Gillem, GA, for his support in providing expert knowledge for this report. Patrick Tanner is President of Tanner and Associates, Champaign, IL. Louis Cohn is a professor and Roddy Williams a research assistant in the Department of Civil Engineering at the University of Louisville, Louisville, KY. The USACERL Principal Investigator was Sandra Kappes. Dr. Michael J. O'Connor is Chief of USACERL-FS. The USACERL Technical Editor was William J. Wolfe, Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL. Dr. L.R. Schaffer is Technical Director.

CONTENTS

	Page
SF 298	1
FOREWORD	2
LIST OF TABLES AND FIGURES	4
1 INTRODUCTION	5
Background	
Objectives	
Approach	
Scope	
2 OVERVIEW OF KNOWLEDGE-BASED SYSTEMS	7
Introduction	
Criteria to Determine Need for a Knowledge-Based System	
3 KNOWLEDGE-BASED TECHNIQUES IN PLANNING, PROGRAMMING, AND BUDGETING RPMA PROJECTS	11
Approach	
Procedure	
Results	
4 DESIGN PROJECT SCHEDULING ADVISOR	29
Approach	
Procedure	
Results	
Prototype Evaluation	
5 CONCLUSIONS AND RECOMMENDATIONS	37

DISTRIBUTION

3

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/ _____	
Availability Codes _____	
Dist	Avail and/or Special
A-1	

TABLES

Number		Page
1	Army Real Property Inventory (1988)	8
2	Listing of Statutory, DOD, and DA Directives	9
3	Project List	18
4	Project Ratings	19
5	Set 1 Ranking	26
6	Set 2 Ranking	27
7	Logic of the Prioritization Process	28
8	DCOST Related to Degree of Difficulty	34

FIGURES

1	Necessary Conditions for Expert System Development	10
2	RPMA Decisionmaking Process	12
3	Inferences Derivable from Facility Number	17
4	Knowledge-Based Rule to Determine Project Design Duration	33
5	Sample Design Project Schedule	35

EMPLOYING EXPERT SYSTEM TECHNOLOGIES TO REAL PROPERTY MANAGEMENT DECISIONMAKING

1 INTRODUCTION

Background

The management of Real Property Maintenance Activities (RPMA) in the Army is a challenging task. The cost of maintaining and operating Army facilities continually increases, while manpower and available resources decrease.

The Army's resource management system consists of the methods, procedures, policy, and resource allocations by which Headquarters, Department of the Army (HQDA), Major Commands (MACOMs), and installations manage Army installation facilities maintenance programs and activities. This is accomplished in five steps:

1. Requirements planning
2. Resource identification and acquisition
3. Resource allocation
4. Program execution
5. Review and analysis.

Each step involves many management decisions. Effective decisions must be made to use scarce resources efficiently.

Efficient management requires experienced personnel with a thorough understanding of the RPMA processes. Unfortunately, the high personnel turnover rate within the Army results in a constant loss of knowledge gained through experience. Since it takes considerable time to train a new employee, many mistakes are made from simple inexperience. Moreover, the complexity of an upper level job can overwhelm even an experienced manager, resulting in poor management decisions.

It may be possible to apply knowledge-based programming techniques to the decisionmaking process, enabling the capture of knowledge from experienced personnel for later transfer to the less experienced. In addition, such applications could provide RPMA managers with "intelligent" tools to help them perform their jobs more effectively.

Objectives

The objectives of this study were to review the Army's real property management system to identify specific areas that could be improved by applying knowledge-based programming techniques, to identify specific decision problems, and to demonstrate applicable knowledge-based techniques.

Approach

Literature searches and informal interviews with selected individuals at installations, MACOMs, and Headquarters, U.S. Army Corps of Engineers (HQUSACE) were conducted to become familiar with the process of managing Real Property Maintenance Activities.

The first of two studies investigated the use of expert systems in facilities engineering. Six areas where expert systems were applicable were determined. Based upon this determination, a prototypical expert system for scheduling design projects within the Engineering Plans and Services Division at an installation was developed.

The second study investigated specific decision problems associated with the planning, programming and budgeting of maintenance and repair projects to determine critical elements and essential analysis procedures required for decisionmaking. Several areas of project management were modeled using knowledge-based techniques.

Scope

This study was limited to the decisionmaking processes involved in managing the planning, programming, designing, and budgeting of real property facilities. It does not include requirements within the Military Construction, Army (MCA) process.

2 OVERVIEW OF KNOWLEDGE-BASED SYSTEMS

Introduction

An expert is someone with significant practical knowledge in a particular domain, who can use that knowledge to analyze a situation and make effective decisions. Expertise consists of heuristic knowledge (or rules of thumb) that allows the expert to use existing information (or knowledge) to reach difficult decisions quickly. For instance, many factors must be considered when determining how to allocate resources for the upcoming fiscal year. Some budget items must be funded, e.g., salaries, while others depend on the availability of funds. The decision to allocate funds is based on an item's importance or priority. Ranking these items by importance to ensure that the most important ones are funded involves a consideration of a great deal of information and depends on the expertise of the decisionmakers. There is no clear cut method to determine priorities; working methods must be derived by expert knowledge.

Knowledge-based systems are computer programs that use knowledge and expertise to derive a solution. They are different from traditional algorithmic programs in that they use reasoning instead of defined procedures to solve problems. The budget allocation problem could not be solved by algorithm because there is no definable series of steps taken to come to a solution. However, the expertise of those involved in the decisionmaking process could be captured and incorporated into a knowledge-based system capable of making "expert" decisions in the budget allocation process.

In the private sector, companies develop knowledge-based systems to obtain a competitive edge. These systems allow them to use available information effectively and to maximize their productivity. Knowledge-based systems are considered essential rather than "nice to have" components of doing business.

The Army must also begin to consider the implementation of expert systems as critical to its success. In fact, the large amount of data required to manage Army programs and the decreasing resources allotted for those programs, as well as the high turnover rates among government personnel combine to make the use of expert systems essential to maintain an effective real property management system.

In 1988, the replacement value of the Army's real property inventory was \$175 billion (Table 1). The cost of maintaining these facilities continually increases, making it more difficult to achieve acceptable standards of maintenance.

The Department of the Army (DA) Pamphlet 420-8, *Facilities Engineering Management Handbook*, (para 1-7) states:

The newly assigned Facilities Engineer (FE) is usually overwhelmed by the assigned duties and often wonders if he/she can ever master all the complexities of the job. Fortunately, he/she has the assistance of skilled technicians with many years of experience in their individual fields. They constitute the backbone of any FE organization, and the emergencies and problems of FE are the accepted way of life for them. [emphasis added]

This statement emphasizes the skill and experience of the FE "backbone," without which the Army could not function effectively. The Army follows the assumption that skilled experts are always available to the FE, when this is not always the case. In fact, the Army is known for its high turnover rate and constant loss of expertise through retirement, job transfer, and duty reassignment. In the Army (as compared to the private sector), proportionately more time is spent learning job skills than exercising those skills on the job because workers spend relatively little time at a single job.

Table 1
Army Real Property Inventory (1988)

Property	Quantity
Total value	\$175 billion
Buildings	1.1 billion sq ft
Railroads	3000 mi
Surfaced areas	650 million sq yd
Acreage	12 million acres
Electric lines	25,000 mi
Water lines	12,000 mi
Sewer lines	11,000 mi

A knowledge-based expert system offers a solution to the problem of loss of expertise due to high turnover rates by capturing the expert knowledge and making it available to new personnel in the absence of the expert source of the knowledge. Use of expert systems could reduce the time spent learning particular tasks and increase the amount of time spent at a level of competent performance. Furthermore, transfer of expert knowledge between systems is easier than a similar transfer of training between individuals; electronic information can be efficiently transported within or between installations by diskette.

Another advantage that expert systems have to offer to the Army is their ability to deal quickly with complex volumes of detail. Decisionmaking in resource management is burdened by the sheer mass of restrictions imposed by policies, guidelines, and regulations. These documents, established by the Congress, the Department of Defense, and the Department of the Army, ensure that funds are used as specified by the law. Table 2 shows a small portion of a subject reference list of general restrictions. This list reflects current annual authorization and appropriation acts and is subject to change upon issuance of new acts. Adherence to these restrictions is FE's responsibility, a task made complex by the bulky paperwork, and difficult by the complex wording of the regulations themselves. To the inexperienced, such regulations are hard to understand and easily misinterpreted.

A knowledge-based system could assist FE personnel in locating and interpreting appropriate regulation documents. The steps used by experts in making decisions that adhere to these regulations could be incorporated into a system which could find pertinent regulations, explain their meaning, and advise correct implementation. Since most failures to follow regulations are unintentional oversights, such assistance would improve adherence to regulations.

Criteria To Determine Need for a Knowledge-Based System

Not every decisionmaking problem requires a knowledge-based system. Certain criteria determine whether development of such a system is feasible and justifiable.

Feasibility is determined through investigation of the task and the expertise needed to perform the task. Interviews with experts involved in the task will show how the task is performed and how expert knowledge is employed to minimize errors and inefficiencies.

Table 2
Listing of Statutory, DOD, and DA Directives

Subject	General Restrictions On	Statute	DOD	DA
Acquisition	Acquisition of land and interests therein by secretaries of military departments.	10 USC 2662 10 USC 2672 10 USC 2675 10 USC 2676 10 USC 2677	DOD Dir 4165.6; DOD Dir 4270.24	AR 420-10 AR 405-80
Commissaries	Use of appropriated funds (in connection with operation of commissaries) for purchase of operating equipment and supplies, and cost of utilities furnished by the Government.	Sec 814, PL 93-437 app'd 8 Oct 74 Sec 814, PL 93-457 (DOD Approp Act, 1975)		AR 30-1 AR 210-20 AR 415-36 AR 415-50
Construction for unforeseen requirements	Cost of construction for unforeseen requirements. (Requires prior approval by SECDEF and report to Congress for construction made necessary by changes.)	10 USC 2673 Sec 103, PL 93-166 (MC Auth Act, 1974)		AR 415-15

Figure 1 shows the conditions that must be met by a decisionmaking task to be considered feasible for system development.

One of the most important conditions is that genuine experts exist. The expert system will attain the skill level of the expert it imitates. Additionally, experts must agree on the derived solutions. Without agreement, there is no way to validate the system's performance.

Once experts are found, they must articulate the methods for performing the task. From this articulation, the system developers can extract the knowledge required to build expertise into the system.

It is not only important that experts perform the task well, but also that they understand the task as a well-structured and precise activity. The structure and precision of the knowledge-based system will reflect the source of expertise.

Finally, complex tasks must be divisible into simple components. Knowledge-based systems are most effective when they deal with a small domain. If the process is extremely complex, requiring large amounts of time to perform, it must be broken into smaller subtasks, which can be considered.

Sometimes the development of a knowledge-based system for a particular decisionmaking process may not be justified. A system must respond to a real need, determined by the potential return on

investment if the system is successful. If the task is already being performed as efficiently as if it were automated, then there is no need for automation, unless its effectiveness depends on an expert doing it.

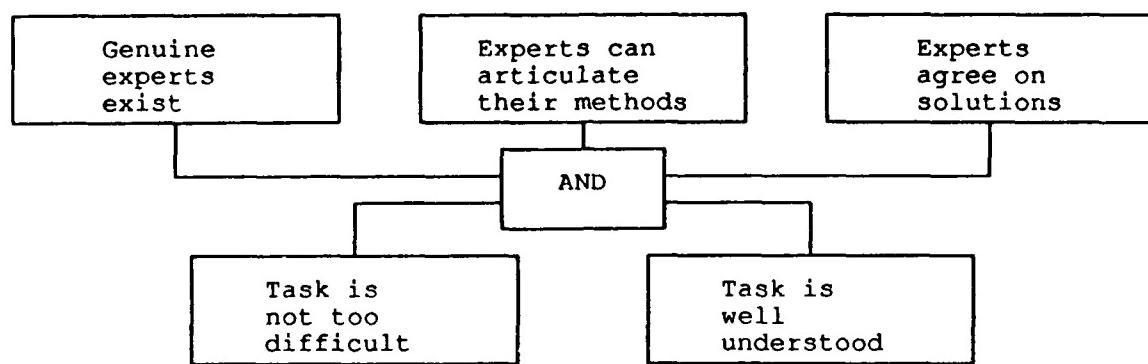


Figure 1. Necessary conditions for expert system development.

3 KNOWLEDGE-BASED TECHNIQUES IN PLANNING, PROGRAMMING, AND BUDGETING RPMA PROJECTS

Approach

Literature searches and interviews with RPMA project management personnel identified the knowledge which relates to specific decisionmaking problems associated with the planning, programming, and budgeting of maintenance and repair projects for real property facilities. Critical elements and analysis procedures required for decisionmaking were determined, and knowledge-based techniques were used to model several areas of project management.

Procedure

Experts in several areas of RPMA management at both the Major Army Command (MACOM) and installation Directorate of Engineering and Housing (DEH) levels were interviewed. After these personnel were briefed on the background, objective, and scope of this research project, they defined the problem to be solved from the perspectives of the MACOM and the installation.

From the MACOM's perspective, a knowledge-based system should determine a balanced and equitable funding distribution¹ for all MACOM Installations that will minimize the risk of funds not being obligated or being used for unintended purposes, and Command and Engineer goals not being met.

From the installation perspective, such a system should develop a list of projects (both financed and unfinanced) in order of priority that satisfies installation Command objectives and maintains the integrity of the installation's facilities.

Interviewees were then asked to describe in some detail their decisionmaking contributions to the overall process, including the kinds of information used in solving their portion of the problem. They were also asked to describe what usually constitutes an adequate explanation or justification of the problem solution.

Results

Overview of the RPMA Decisionmaking Process

Figure 2 depicts several components of the RPMA decisionmaking process that involve expertise at both the MACOM and installation levels. Most of the areas shown relate to planning and programming of K and L (Army Management Structure [AMS] Key Accounts) projects. However, all RPMA accounts are included in the prioritization of unfinanced requirements at the MACOM level.

Annual Recurring Requirements. RPMA requirements are composed of the annual recurring requirements needed to operate and maintain the Army's real property inventory, as well as one-time

¹Note that the challenge here is one of arriving at a balanced *fund distribution* and not a balanced budget. Practically speaking, a balanced budget is unattainable, being a case where funding equals requirements.

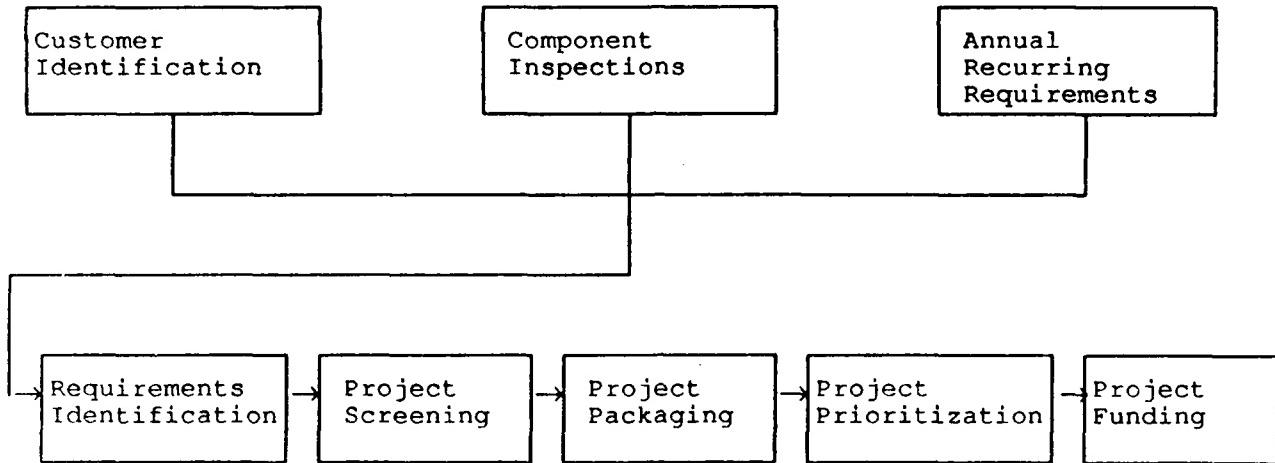


Figure 2. RPMA decisionmaking process.

requirements. One-time requirements include changes in mission, programs, and operational needs and needs which result from natural disasters. RPMA requirements are identified by DEH customers, shop personnel, PM teams, and estimation techniques.

Customer Identification. Prior to the installations preparation of the Command Operating Budget (COB), usually from February to March each year, the DEH contacts its customers (e.g., brigade and battalion commanders) and asks for the top 10 projects in each of the .K and .L accounts. Project lists with accompanying work orders are returned to the DEH in the customer's priority order.

Component Inspection. All newly identified actions go through a screening process to ensure that duplicate work orders are not created and to ensure that requirements are not overstated by double counting projects already included as part of a larger project. Projects in excess of \$50,000 are validated, generally by a facility or component inspector.

Once the DEH's requirements have been screened, a senior manager in the DEH organization (e.g., Deputy DEH, Engineer Resource Management Division [ERMD] Chief) sorts though and reads every project in the stack of work orders. Projects are initially classified as high, medium, or low priority in consideration of both engineering and mission support priorities. If the number of high priority projects is large, they go through further ranking to reduce the number. The remaining projects are then ranked numerically. The same process occurs for all of the low and medium priority projects until one prioritized project list is produced for review and approval by the installation commander.

Requirements Identification. Projects and other requirements that do not have a sufficiently high priority to fall within the area of fund availability become unfinanced requirements (UFRs). High priority/mission essential UFRs become candidates for "Subject to the Availability of Funds" (SAF) funding during the current execution year's end or for inclusion as high priority items in the following year's program. Installations submit lists containing UFRs to MACOM headquarters, where MACOM

resource managers establish a single, prioritized UFR list to use as a basis for fund distribution if migratory funds become available.

Key Decision Areas

Areas where many decision rules are applied are depicted by the bottom row of boxes in Figure 2. The number of decision rules varies from a handful (perhaps 30) to a potentially large number (as many as 50 or more). Those areas with relatively few rules are briefly described, while those with many rules require longer, illustrative examples. The primary intent of the discussions is to demonstrate whether or not the knowledge rules employed are sufficiently structurable for a knowledge-based programming environment.

Project Screening. Identified requirements may have previously been identified or programmed. Thus, a screening process is performed at work order reception and other levels within the ERMD. The process consists of searching work orders (DA Form 4283) by facility number, and of breaking each work request into its components or disciplines. If a requirement has already been identified, customers may be authorized to handle the project through the Self-Help Program. Projects of this nature do not require the knowledge of a skilled craftsman. As the name implies, this program gives customers guidance on how to proceed with the work themselves. If the project has not already been identified by the customer, the Job Order Contracting (JOC) project manager and the Engineer Design Branch generate project lists to see if the project has already been programmed or if it is in progress. Projects in other systems (i.e., the Integrated Facilities System² [IFS] or the DD Form 1391 Processor) contain a "Remarks" data field noting whether the customer's project has already been identified or included as part of a larger project. If the search succeeds, the customer is advised of the project status. If the search fails, the requirement may be considered for inclusion in some other project.

Project Packaging. Projects are generally put together in one of two ways, depending on the type of facility involved. Both family and unaccompanied personnel housing requirements are generally packaged by components within facilities. But in other facilities (e.g., training centers, ranges, command posts, etc.), projects are put together based on a total building concept. This approach corrects as many deficiencies as possible within a facility in the same project. The driving philosophy behind the total building concept is not one of engineering or economy, but of minimizing disturbances to customers. If a project packaged by the total building concept is too expensive relative to other funding requirements, it can then be packaged by components across facilities.

Project Validation. The last step in determining the scope of a project is validation. A project is valid if it meets both engineering and governing regulation requirements. From an engineering standpoint, validity is determined by on-site inspection by a facility or component inspector. In one case, a work request was submitted to replace the entire lighting system in a building. Upon inspection and measurement, the lighting system turned out to be adequate according to generally accepted standards. The request was invalid. From the standpoint of governing regulations, a project is valid if it meets the appropriate cost limitations and has the proper approval.

Some sample governing regulations are:

1. Cost must be less than 50 percent of replacement.
2. Projects for WWII building maintenance and repair must cost less than \$20 per sq ft (0.093 m²).

²For information and technical support regarding IFS, contact the U.S. Army Engineering and Housing Support Center, Directorate of Systems Integration, CEHSC-S, Fort Belvoir, VA 22060-5580, (703) 355-2522.

3. Average annual maintenance costs for family housing must be less than \$15,000 per dwelling unit, \$25,000 if general, flag officer quarters.

4. Total .L Account expenditures must be less than 10 percent of the sum of .K and .L Account expenditures.

5. Minor construction projects with a funded cost of more than \$500,000 will be approved by the Secretary of the Army.

6. Minor construction projects with a funded cost of more than \$200,000 will be approved by the Assistant Chief of Engineers.

7. Minor construction projects with a funded cost of \$200,000 or less will be approved by the MACOM commander unless the MACOM commander has delegated this authority to the installation commander.

8. The appropriate committees of Congress will be notified in writing of the Army's intent to award a minor military construction project with a funded cost in excess of \$500,000. The notification will include the project justification and estimated cost. The work may not be carried out until 21 days following the receipt of notification by the committees unless each of the committees consents to a waiver of the 21 day period. Notifications are normally made monthly.

9. Certain approved projects must be resubmitted for reapproval prior to award. These include projects not under contract award within 8 months after project approval and those significantly revised following congressional notification.

10. The nonappropriated fund managers have authority to approve certain construction projects. These projects must conform to the space criteria specified in *Architectural and Engineering Instructions* (HQUSACE, 14 July 1988) Ch 5 and Appendix A, must be funded solely from nonappropriated or private fund sources, and must cost more than \$200,000 and less than \$500,000. Projects of this type costing less than \$200,000 require MACOM approval. Projects over \$500,000 require approval by the Secretary of the Army. Only projects over \$500,000 require approval by the Secretary of the Army.

Project Prioritization. Project prioritization at the installation level is an ongoing activity. A master priority list is developed during preparation of the Command Operating Budget. Documentation on each project is reviewed by a senior staff member of the DEH (usually the ERMD Chief or the Deputy DEH), who has a general knowledge of the condition of the installation's facilities, an explicit knowledge of the commanding general's priorities, and a good idea of expected funding levels for the upcoming fiscal year.

With this knowledge, the senior staff member initially classifies projects as high, medium, or low priority. High priority projects are those which deal extensively with fire, safety, health, high visibility infrastructure, and legal concerns (with the Occupational Safety and Health Administration [OSHA], the Environmental Protection Agency [EPA], etc.), and/or are highly political (i.e., some commanding general wants it). Medium priority projects have the same characteristics as high priority projects, but to a lesser degree.

Five project factors taken into consideration during the prioritization process are listed below. Subfactors are listed in descending order of importance.

1. Functional use of the facility. Major functions of facilities are:

- operational and training facilities

- critical utilities systems
- unaccompanied personnel housing and dining
- medical facilities
- maintenance facilities
- community facilities
- family housing
- roads
- production facilities
- supply facilities
- administrative facilities
- railroads and fencing
- research facilities
- real estate.

2. Justification factor. Projects are justified by their purposes:

- health/safety
- environmental conditions
- physical security
- mission/readiness (major impact)
- mission/readiness (some impact)
- morale, welfare, recreation
- command interest
- cost effectiveness
- pollution abatement
- quality of life
- security of occupants/property
- mission/readiness (minor impact).

3. Component criticality. Criticality refers to the importance of repairing a component to the well-being of the whole facility. While it is possible for criticality to vary (e.g., a roofing project which consists of gutter replacement may be less critical than a ground cover project which consists of repair to antenna fields), the major subfactors are listed below in descending order of importance:

- structure
- utility plant equipment
- utility systems (electrical, heating, plumbing)
- utility distribution/collection
- appurtenances
- roofing
- installed equipment
- pavement
- railroads
- ground cover
- floor covering
- exterior paint
- drainage
- air conditioning
- recurring maintenance calibration and inspection
- forestland
- fish and wildlife.

4. Condition of the facility with reference to degree of deterioration. A project may gain importance by the degree of deterioration that will occur if the project is not accomplished in the next year because:

- equipment or facility has failed and cannot be used for its intended purpose
- failure is imminent; system is in an advanced stage of deterioration
- system is functional but deterioration will progress if project is not accomplished
- little deterioration at present, but work is still considered essential.

5. Installation priority. The installation commander, DEH, or installation planning board may assign importance to a project as a matter of policy. The factors taken into consideration are many and include anything from mission readiness to political or even cosmetic factors.

Each facility number in the Army's inventory of real property is related to a construction category code, and each facility can be broken into its component parts. The construction category code generally refers to the functional use of the facility (Factor 1). Facility components refer to the component criticality (Factor 3). A combination of the facility number and component in question can determine the relative weight of two of the project factors. Figure 3 illustrates this relation.

Tables 3 and 4 show how projects were prioritized by a high, medium, or low rating, according to the given line of reasoning.

Overall funding priorities are derived from the many facts and rules of operation for a DEH organization and the individual posture of a particular installation. Those requirements not funded for the current fiscal year demand a separate prioritization, to rank them for receipt of new funds that may become available, or for inclusion in the requirements for the following fiscal year. Below are given sample facts and rules that represent the contents of a hypothetical expert system that could help decide the priority of an installation's unfinanced requirements from a MACOM point of view. Their contents are plainly stated in English language rather than in the symbols of first order logic or predicate calculus, although a translation into either logical language is possible. Some of the rules actually represent rule schemas, which could be developed fully in a more detailed effort.³

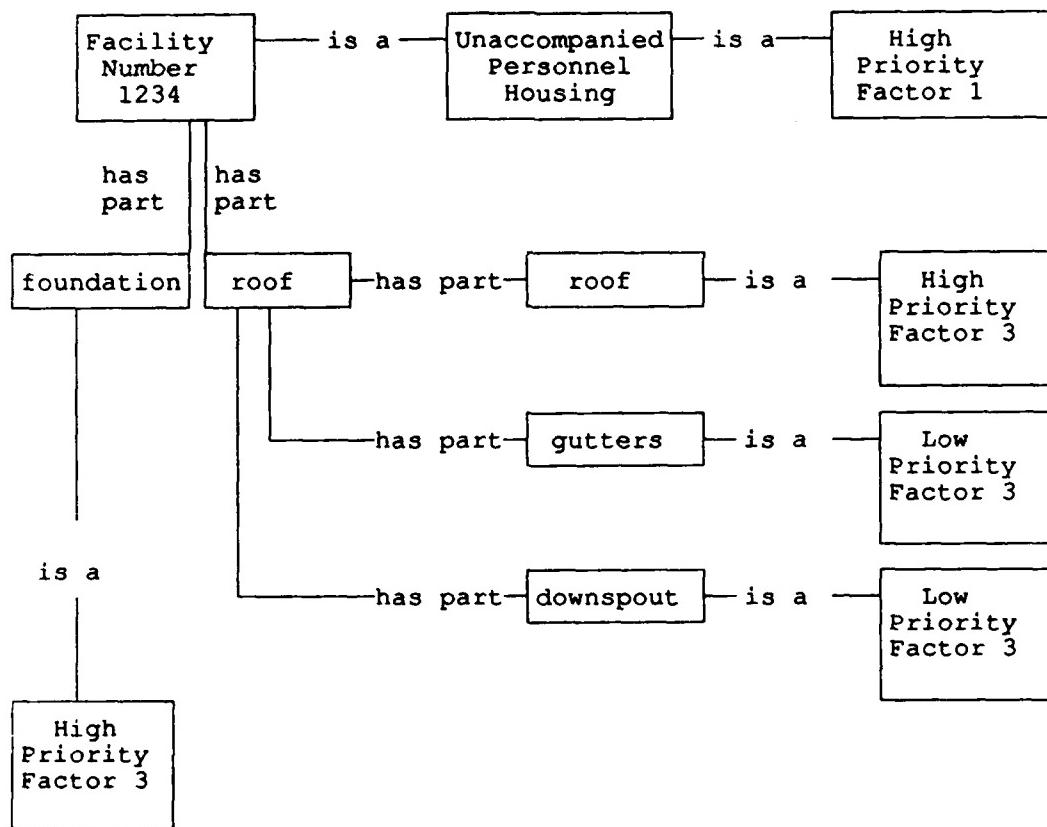


Figure 3. Inferences derivable from facility number.

³ For example, in rule 14, all of the specific actions that must be accomplished ahead of programming an MCA project could be listed, possibly in required chronological sequence, and all of the factors that affect each installation's mission could be given measures of relative importance. This could result in a numerical ranking by importance. Similar remarks hold in the case of Rule 15.

Table 3
Project List

Number	Description
1	Repair electrical wiring from the tower to firing lanes in a training range
2	Repair/replace light fixtures in administrative building
3	Repair sewer line
4	Repair Honeycutt Gym
5	Install automatic door locks
6	Install washers and dryers

Some of the sample DEH facts are:

1. Each installation's Annual Recurring Requirement (ARR) for each key account (.J, .K, .L, .M)
2. Total dollar amount of unfinanced requirements
3. Overall condition of each installation's facilities
4. Type of installation
5. Installation priority
6. Type of component
7. Method of accomplishment
8. Army Management Structure (AMS) code
9. Sensitivity of component to variations in weather conditions
10. The total dollar amount spent on .K and .L account projects must be such that:

$$\text{Total } \$L < 10\% (\$K + \$L) \quad [\text{Eq 1}]$$

where \$L = the dollar amount in the .L account
 \$K = the dollar amount in the .K account.

Table 4
Project Ratings

Number	Rating	General Reasoning
1	Medium	Since the training range is still functional, the priority is lowered. The fact that a training range is a highly important mission support facility prevents a low priority rating.
2	Medium	This administrative building is part of a U-shaped complex of buildings which all need an entire electrical system upgrade. This would be part of a program that has already upgraded around 20 1940s-vintage mess hall buildings which will also eventually need an electrical upgrade. The system is not failing, but since the small battalion that occupies the facility controls administration for the entire mission, the priority is raised to medium.
3	High	These sewer lines are near a mess hall used by most troops, the welcome center, and central issue. The broken lines result in a tremendous roach problem and cause health risks.
4	High	Work on Honeycutt Gym has been a long deferred project due to a lack of funding. It is a high morale item for the troops and one of the commanding general's highest priorities.
5	Low	The installation of automatic door locks is not a physical security issue, since the criminal investigation division already has door locks on the building. This division wants a buzzer system to control entrance to the building. The present system still works well. This is a "nice to have" item.
6	Low	The requested washers and dryers are for Building 912, a barracks that already has some washers and dryers. Since troops are issued only four sets of clothing and must always have clean sets, they want more washers and dryers. However, since there is a base laundry contract that the troops can use, the request is assigned a low priority.

Some sample installation rules are:

1. Any requirement for funding outside the RPMA area is not within the scope of this analysis.
2. During a funding decrement exercise, those installations with relatively few troops available for borrowed military labor are funded at a proportionately higher level than those installations with many troops.
3. If the difference between the date of calculation and 1 September of the Current Fiscal Year is fewer than 30 days, and if the percent design complete is less than 95, consider the project nearly ineligible for funding (.99 Certainty Factor [CF]) for this fiscal year.

4. In case of a tie among competing priorities, put Fort X ahead of all others since it is being upgraded from a Housekeeping Installation to a Division Installation.
5. When there is a surplus of funding in the .J account, give highest priority to .M account UFRs since the .M account is always underfunded.
6. If there is a pay raise on 1 January, then a UFR for pay of personnel *may* be a legitimate requirement, depending on the appropriation bills and DA requirements.
7. Surgeon General-related requirements generally will have a high priority.
8. When two or more UFRs are of the same general priority, give a higher priority to those items whose failure is imminent.
9. Fund no items whose required lead time for funding would obligate the funds after they expire.
10. If a high priority UFR becomes critical, contact personnel at the installation to have them reprogram from existing funds and submit a UFR for the lesser priority item removed from funded requirements.
11. If a potential safety hazard exists in a facility which has not yet failed, and if the unsafe area can be put off limits to temporarily eliminate the hazard, then defer funding if there is no more available.
12. Travel and training support are not valid requirements for year end funding. Installation personnel should put these requirements in their core dollar request.
13. Money for design of specific RPMA Projects is critical. Nonspecific RPMA projects receive extremely low priority.
14. Work that must be accomplished ahead of funding a specific MCA project that is critical to an installation's mission has a high priority.
15. If a facility or facility component used to support an installation's training mission has failed, assign a high priority to the requirement. If there is another facility which could temporarily fulfill the need for training, assign a medium priority to the requirement.
16. If a planning or analysis funding request precedes the programming of an MCA project and if the number of MCA projects at any installation is uncommonly high (i.e., exceeds five), contact installation personnel for more information on the number and type of MCA projects.
17. If two or more distinct UFRs for work from the same installation lie ahead of programming an MCA project, and if there are inconsistencies in the UFRs, contact installation personnel to clarify the inconsistencies.
18. It is inconsistent to request funding for master planning of an MCA project without requesting funding for economic analyses (or vice versa).
19. Items that affect the health, safety, or welfare of troops are second only to Surgeon General-related items.
20. Items that affect morale and welfare of troops and their living quarters are of a higher priority than items that affect morale and welfare of troops related to their recreational facilities.

21. Maintenance and repair projects that prevent expensive facility components from deteriorating rapidly and that affect morale, welfare, or recreation of troops are of a high priority.
22. If the heating, ventilation, and air-conditioning (HVAC) systems fail, then the internal facility components are subject to extreme weather variations.
23. If the gymnasium floors are deteriorated, then the morale, welfare, and recreation of troops are affected.
24. If a component is gymnasium floors, then component cost is high.
25. If a component is gymnasium floors, then component is sensitive to extreme weather variations.
26. If a component of a facility is sensitive to and subjected to extreme weather variations, then it will deteriorate rapidly.
27. If a component of a facility has failed and will cause failure of other components of the facility, assign the corresponding maintenance and repair project a high priority.

A system based on these facts and rules should meet these stated goals:

1. The system should help to pare down the number of UFRs by eliminating low priority funding requests from those that must be funded this year, or by eliminating UFR's that can be included in the next year's budget, or by reducing the level of services to a minimum acceptable level.
2. The system should determine UFR priorities, show a total dollar amount of requests and draw a funding lines at the first UFR in the prioritized list where costs exceed available dollars.
3. The system should total dollar amounts by the key account (.J, .K, .L, .M) for each installation.
4. The system should group low priority items that fall below the funding line for possible inclusion in the following year's Command Operating Budget.
5. Whenever more information about a UFR is required, the system should eliminate it from the list of priorities until that information is obtained.

Example of the RPMA Decisionmaking Process

This example demonstrates the feasibility of prioritizing two sets of UFRs using the facts and rules gathered from experts during the interview process.

Set 1.

Requirement 1.

1. TITLE: Design FY89 projects
2. INSTALLATION: Fort Gillem
3. INSTALLATION PRIORITY: 14
4. TOTAL DOLLARS (x 1000): 300

5. METHOD OF ACCOMPLISHMENT: Contract

6. AMS CODE: 202694.M

7. DESCRIPTION/JUSTIFICATION: Design FY89 projects. Funds are required to have architect-engineers design the projects programmed for accomplishment in FY89. There are 15 projects ready to be designed. Completion of designs prior to or early in FY89 will ensure that projects are awarded in the first or second quarter of that fiscal year and that obligation targets will be met. Also, there will be less pressure early in the year on the workload of both the legal and procurement staffs when verifying the drawings and technical specifications for accuracy and conformation to regulatory requirements before going out for bid. A side benefit would be use of migratory funds by having projects available "on the shelf" for award at year's end.

Requirement 2.

1. TITLE: Install PAPI system

2. INSTALLATION: Fort Hood

3. INSTALLATION PRIORITY: 15

4. TOTAL DOLLARS (x 1000): 100

5. METHOD OF ACCOMPLISHMENT: Contract

6. AMS CODE: 202694.L

7. DESCRIPTION/JUSTIFICATION: To purchase/install the following: one 881 PAPI system to include one PAPI-400 with two projects and on/off monitoring for installation at the approach end of runways 14 and 32; one optical bench; one clinometer/leveling device. The system will provide pilots specific glide path information to carry out their approach to the airfield more accurately and safely. This is important when making approaches during night or bad weather, when it is difficult to judge altitude, rate of closure, and glide path of the aircraft. If work is not accomplished, safety of aircraft personnel and passengers will be affected at night or during inclement weather.

Requirement 3.

1. TITLE: Manhole repair

2. INSTALLATION: Fort Campbell

3. INSTALLATION PRIORITY: 15

4. TOTAL DOLLARS (x 1000): 400

5. METHOD OF ACCOMPLISHMENT: Contract

6. AMS CODE: 202694.K

7. DESCRIPTION/JUSTIFICATION: Contract funds (\$400k) are required for project F5-310-7J to repair/replace manholes that could cave in, stopping all flow of sewage from the hospital and housing areas to the waste water treatment plant. Such an emergency would require closing the road and pumping

sewage to the plant. The facility engineer has designated this requirement to be a bona fide need for FY88.

Requirement 4.

1. TITLE: Parapet cap/stairway
2. INSTALLATION: Fort Hood
3. INSTALLATION PRIORITY: 16
4. TOTAL DOLLARS (x 1000): 150
5. METHOD OF ACCOMPLISHMENT: Contract
6. AMS CODE: 202694.K
7. DESCRIPTION/JUSTIFICATION: To repair deteriorated masonry joints and parapet caps along top perimeter rim of buildings 667, 668, 669, and 670. Existing condition of masonry presents a potential safety hazard. In order to prevent further structural deterioration, masonry joints must be repaired.

Requirement 5.

1. TITLE: Archeological/historical survey
2. INSTALLATION: Fort Riley
3. INSTALLATION PRIORITY: 16
4. TOTAL DOLLARS (x 1000): 3
5. METHOD OF ACCOMPLISHMENT: Contract
6. AMS CODE: 202694.M
7. DESCRIPTION/JUSTIFICATION: The state historic preservation office has requested that Fort Riley conduct a survey of the proposed area prior to construction. This survey will ensure compliance with the National Historic Preservation Act of 1966, as amended, and the Archaeological Resources Protection Act of 1979. The construction cannot begin until the survey is completed. The project will be delayed if the survey is not completed this fiscal year. No part of this UFR is funded in FY88.

Set 2.

Requirement 1.

1. TITLE: Travel and training support
2. INSTALLATION: Fort Polk
3. INSTALLATION PRIORITY: 18
4. TOTAL DOLLARS (x 1000): 1

5. METHOD OF ACCOMPLISHMENT: Contract

6. AMS CODE: 202696.H

7. DESCRIPTION/JUSTIFICATION: Funding is required for TDY/technical training for specific software applications; equipment training for print plan employees; training in customer service-related regulatory administrative requirements; FORSCOM-directed conference, etc.

Requirement 2.

1. TITLE: MCA project analysis

2. INSTALLATION: Fort Bragg

3. INSTALLATION PRIORITY: 18

4. TOTAL DOLLARS (x 1000): 30

5. METHOD OF ACCOMPLISHMENT: Contract

6. AMS CODE: 202694.M

7. DESCRIPTION/JUSTIFICATION: Financing is required for preparation of economic analysis work as part of DD Form 1391 documentation on 10 FY92 MCA projects for Fort Bragg. Complete documentation is required in FY88 to keep projects in the construction program for FY92. Projects include training ranges, administrative facilities, and a child development center. These projects are required to meet mission requirements and scheduled equipment and system upgrades. Failure to complete the required documentation for congressional project approval will cause delayed or lost projects and negatively affect mission accomplishment. No part of this UFR is funded in FY88.

Requirement 3.

1. TITLE: Replace pneumatic control

2. INSTALLATION: Fort Campbell

3. INSTALLATION PRIORITY: 18

4. TOTAL DOLLARS (x 1000): 200

5. METHOD OF ACCOMPLISHMENT: Contract

6. AMS CODE: 202694.K

7. DESCRIPTION/JUSTIFICATION: Contract funds (\$200k) are required for project F6-15-4P, replacement of pneumatic controls in Long Gym, where existing controls have failed, leaving the building without temperature/humidity controls. This project is required to prevent further building deterioration and increase building use. The facility engineer has designated this requirement to be a need for FY88.

Requirement 4.

1. TITLE: Air condition enlisted barracks

2. INSTALLATION: Fort Riley
 3. INSTALLATION PRIORITY: 19
 4. TOTAL DOLLARS (X 1000): 1,848
 5. METHOD OF ACCOMPLISHMENT: Contract
 6. AMS CODE: 202694.K
7. DESCRIPTION/JUSTIFICATION: Funds are required for FE-00054-7P (et al.) to air condition enlisted barracks located in the 3700 block. The project was previously FY87 SAF; however, drastic AFP decreases cancelled the project award. Upcoming warm weather will require repair of component parts of the air conditioning system by in-house personnel (a temporary solution). Project cost will escalate. Failure to fund project would cause a carry-over of requirement to FY89 and further deterioration of structure. No part of this UFR is funded in FY88.

Requirement 5.

1. TITLE: Master planning
 2. INSTALLATION: Fort Bragg
 3. INSTALLATION PRIORITY: 20
 4. TOTAL DOLLARS (X 1000): 40
 5. METHOD OF ACCOMPLISHMENT: Contract
 6. AMS CODE: 202694.M
7. DESCRIPTION/JUSTIFICATION: Financing is required for development of the administrative area site, according to the new master land use plan. Site plans are required for DD Form 1391 documentation on four FY92 MCA projects at Fort Bragg. Complete documentation is required in FY88 to keep the projects in the construction program for FY92. Failure to complete the required documentation for congressional project approval will cause delayed or lost projects and negatively affect mission accomplishment. No part of this UFR is funded in FY88.

Requirement 6.

1. TITLE: Modify showers and tubs
2. INSTALLATION: Fort Douglas
3. INSTALLATION PRIORITY: 20
4. TOTAL DOLLARS (X 1000): 523
5. METHOD OF ACCOMPLISHMENT: Contract
6. AMS CODE: 202694.K

7. DESCRIPTION/JUSTIFICATION: Project FY 153/6J will replace showers and tub/showers. If this work is not accomplished, the showers and tubs will continue to leak and damage the surrounding area, especially second or third floor facilities, which will continue to damage the ceilings below. Many of the units now have mold, peeling paint, or fungus and military personnel can not keep them clean. Many of these buildings do not pass inspection. This situation may deteriorate until health conditions are endangered. In this case, the units would be placed off limits, and the occupants would be forced to double up in another bathroom.

Prioritization Process.

Tables 5 and 6 show the ranking/status of each UFR in Sets 1 and 2 according to the overall structure (Facts, Rules, Interpreter, Scheduler) of the sample expert system set forth above.

The actual sequencing of rule application for Requirement 3 in Set 2 could happen in a backward chaining fashion, symbolized as follows:

Let:

- A = Type of component (floor, roof, HVAC system, etc.)
- B = Failed component (floor, roof, HVAC system, etc.)
- C = Type of facility use (gymnasium, barracks, etc.)
- D = Effect on morale, welfare, and recreation (high, medium, low)
- E = Sensitivity of component to weather variations (high, medium, low)
- F = Priority relation to Surgeon General items (first, second, third, etc.)
- G = Priority relation to living quarters (high, medium, low)
- H = Final priority (high, medium, low)
- I = Cost of component (high, medium, low)

Table 5
Set 1 Ranking

Requirement Number	Final Ranking/Status	Rule(s) Applied
1	5	13
2	3	15
3	1	7, 8
4	4	11
5	2	8, 10

Table 6
Set 2 Ranking

Requirement Number	Final Ranking/Status	Rule(s) Applied
1	Not Valid	12
2	Need Information	17, 18, 19
3	3	20, 21, 22-27
4	2	20, 21
5	Need Information	18, 19
6	1	20, 21, 7, 26

J = Degree of subjection to weather variations (high, medium, low)

K = Rate of deterioration (high, medium, low)

L = Type of UFR (maintenance and repair project, utility, engineer service, etc.)

M = Maintenance and repair/replacement item (component of facility, entire facility, improved grounds, unimproved grounds, etc.).

Some of the applicable rules can be symbolized as follows (" → " denotes implication and " & " denotes conjunction):

Rule 22: (E & L & I & K & D) → H

Rule 23: B → J

Rule 24: (C & A & K) → D

Rule 25: (C & A) → I

Rule 26: (C & A) → E

Rule 27: (M & E & J) → K.

Table 7 illustrates the facts and rules, and repeated applications of Modus Ponens.⁴

⁴The Rule of Modus Ponens says that from the statements ($P \rightarrow Q$) and P, we can infer Q.

Table 7
Logic of the Prioritization Process

	Using:	Infers:
Rule 22 and		
Facts	E (component sensitive to weather variation) L (project is maintenance and repair) I (component cost is high) K (rate of deterioration is high) D (morale, welfare, and recreation are affected)	H (priority is high)
Rule 23 and		
Fact	B (failed component [HVAC])	J (internal facility components [i.e., gym floor] are subjected to weather variations)
Rule 24 and		
Facts	C (facility is gym) A (component is floor) K (rate of deterioration is high)	D (morale, welfare, and recreation are affected)
Rule 25 and		
Facts	C (facility is gym) A (component is floor)	I (component cost is high)
Rule 26 and		
Facts	C (facility is gym) A (component is floor)	E (component is sensitive to weather variations)
Rule 27 and		
Facts	M (maintenance and repair item is facility component) E (component is sensitive to weather variations) J (component is subjected to weather conditions)	K (rate of deterioration is high)

4 DESIGN PROJECT SCHEDULING ADVISOR

Approach

Areas within the Facilities Engineering (FE) organization where knowledge-based technologies could be applied were investigated through literature search and personnel interviews. From this process it was determined that a significant problem facing FE personnel is the management and scheduling of design projects. Further investigation was done to develop a prototype expert system to determine the feasibility of an expert system to manage and schedule design projects.

Procedure

The knowledge acquisition process for the development of the prototype system consisted of several installation site visits and personnel interviews. A review of Army regulations and DOD pamphlets identified the regulatory constraints placed on the design management process.

Based on the knowledge gained through site visits and the suggestions from the facility support staff at the Army Corps Louisville District, the Lexington Bluegrass Army Depot was selected as the laboratory for prototype development. The staff, though small, had both the experience and knowledge of the procedures and regulations required of excellent subjects for knowledge acquisition research.

The Engineering Plans and Services (EP&S) Division is responsible for the design of minor construction, and maintenance and repair projects at an installation. Based on funding and time constraints, decisions are made to design projects in-house, contract them to architectural/engineering (A/E) firms, or backlog them until funding is available. To maximize use of in-house staff and to decrease the need for contracting, it is important that the design scheduler consider all parameters affecting the cost and completion time of design projects. Effective design scheduling is a skill obtained through experience. The Design Project Scheduling (DPS) Advisor attempts to capture this expertise to assist both new and experienced design schedulers.

The DPS Advisor system must consider the unforeseen circumstances that would force changes upon existing schedules: in-house workload, seasonal weather constraints, funding constraints, design difficulty, and project priority. Schedules generally list projects by priority and engineering discipline and indicate which projects require no design, which should be designed by an A/E firm, or which may be backlogged.

Results

Knowledge Requirements

In general, the prioritized project list drives the order of project design. However, later decisions that affect the scheduling process are based on the following factors:

1. Unforeseen circumstances
2. Political factors (change in commander and shifts in priorities)
3. Workload of in-house personnel (manhours)
4. Seasonal weather constraints
5. Design difficulty.

An unforeseen circumstance might be a safety and health emergency which demands immediate attention. For instance, if the roof of a building were to fail, an engineer would immediately be required to produce a roof design. This would require the engineer to postpone work on a current project to turn attention to the emergency design. If several such situations arose, a backlog of design projects would be produced. The design of these projects may then be contracted to an outside design firm in order to meet the fiscal year deadline. This would lead to higher costs but would have the advantage of meeting the design schedule.

Political factors are another concern of the Facilities Engineer, due primarily to the biannual rotation of installation commanders. Each commander brings priorities which affect the design division. New commanders who arrive during a fiscal year often create new projects according to different priorities. These changes reorder established priorities and usually require completion of the new project designs before the end of the fiscal year. This may delay the scheduled completion of ongoing projects, and may create additional repair and maintenance activities in those facilities affected by the delays.

The design staff manager must distribute in-house workload (available manhours) to accomplish the scheduled tasks. The Army has documented procedures to accomplish each type of task, but official Army procedures need to be amended often to accommodate real life situations. Experienced design managers must balance available resources and project demands.

The design section manager must also consider weather constraints. Sometimes the design engineer may plan to complete the design before the end of the year, and later find that construction has been delayed by weather conditions.

Design difficulty is measured on a scale from one to nine (nine being the most difficult), and refers to the length of time and experience required to prepare a design. For example, the design of a handicapped ramp for attachment to a building entrance would entail a relatively low degree of difficulty; the job could be successfully performed by an engineer with little experience. However, renovation of a large structure, which would include a complex coordination of many projects, would demand much design time and expertise; the level of design difficulty would be high.

System Development

The Design Project Scheduling (DPS) Advisor is a program which coordinates the various project design parameters, and prioritizes project schedules, according to a determined standard. This system was written using the microcomputer-based expert system development tool EXSYS.⁵ Data on design projects is stored using the database management system dBASE III PLUS.⁶ A program written in Turbo Pascal⁷ serves as the control structure, providing access by the EXSYS code to the dBASE III PLUS data files.

The system consists of two knowledge bases, an inference engine, and a working global database. The knowledge base contains domain and heuristic knowledge associated with the management and scheduling of design projects. The inference engine organizes and controls the steps taken to resolve scheduling problems. The global database sets up a user interface, and keeps track of all the data required to describe and manage each particular project. There are five separate database files within DPS Advisor. The first of these five data files contains information on all new projects input into the system, and the other four contain information on currently scheduled projects in each design discipline (Civil, Electrical, Mechanical, and Environmental).

⁵EXSYS is a trademark of EXSYS, Inc.

⁶dBASE III Plus is a trademark of Ashton-Tate.

⁷Turbo Pascal is a trademark of Borland International.

DPS Advisor contains two separate knowledge bases--PTYPE and LBG. PTYPE determines the type of project and whether the construction season should be considered, and LBG determines the time it would take to design the project, whether the design should be performed in-house or contracted to an A/E firm, whether it is a possible backlog project, or whether the project requires an engineering design.

The global database contains the following information for each project:

- number
- date entered into the system
- title
- status
- type (by engineering discipline)
- estimate
- seasonal constraints
- degree of design difficulty
- command priority
- documentation flag (indicating completion of DD Form 1391 and 2701).⁸

The project type and seasonal constraints are determined by rules in the PTYPE knowledge base. The user matches the project type from the work order description with each possible project. This feature helps work order clerks unfamiliar with project types to correctly categorize new projects.

The dBASE III PLUS program allows the user to edit data on any project in the database. The program is menu driven and allows the user to search all project records, either by record number or project description.

Once the user has entered all of the required information concerning a project or projects, the scheduling process is begun by returning to the main menu and selecting the "BEGIN SCHEDULING" option. This option takes the projects from the initial database file and transfers that data into EXSYS. EXSYS then takes the data and determines the necessary information needed to produce a work schedule for each engineering discipline.

The process of transferring data from dBASE to EXSYS required the construction of an interface program. The program "DBDATA," written in Turbo Pascal, converts dBASE data into EXSYS format.

Upon completion of this procedure, the LBG knowledge base determines the design time and related design management information for each project. The information produced for each project is output to a data file. This data is then converted back into Dbase III format by the Turbo Pascal program "SCHED." The "SCHED" program formats the data for inclusion in a separate file with other data for a particular engineering discipline. The dBASE files are then indexed by priority, and the design completion date is determined by summing the design times for each record. (A/E projects are not

⁸Project Approval and Family Funding Form 2701 is local to Lexington Bluegrass Army Depot, Lexington, KY.

considered in this particular computation because they are not performed by in-house labor). The schedules are then produced; probable workshop projects are listed first, followed by priority one through nine projects.

The Lexington Bluegrass Army Depot, Lexington, KY has developed the following installation command priority rating system:⁹

- priority 1: projects that correct conditions of such an emergency that human life or governmental property is endangered and immediate action is required
- priority 2: projects that eliminate probable fire, safety, or health hazards and correct probable security deficiencies involving classified materials
- priority 3: projects considered to be of such an emergency that failure to accomplish them would cause embarrassment to the depot and tenant activities or result in serious consequences that would warrant accomplishment by most expedient methods
- priority 4: projects that provide facilities or correct deficiencies that are immediately required to perform the organization's mission or meet specified commitment
- priority 5: projects that correct deficiencies not involving classified materials
- priority 6: projects that provide facilities or correct deficiencies in organizations that are required for an organization to accomplish its mission effectively without undue hardship
- priority 7: projects that correct deficiencies to prevent major repairs in the foreseeable future
- priority 8: projects that improve facilities or property that will result in a significant savings in labor or material
- priority 9: projects to correct minor deficiencies or make minor improvements in facilities or operations.

The command priority is an important factor in the scheduling process. The above criteria are primary in determining the order of the project design schedule by DPS Advisor. The DPS Advisor objectifies schedule priorities, and can minimize later changes in the ordering of scheduled projects.

The knowledge bases determine the time necessary to design projects based on command priority and design difficulty. They also determine the project type and seasonal constraints. The time required to design a given project is determined by dividing the design cost by the engineer's hourly rate. This value is multiplied by a factor to account for design difficulty. The total number of hours to design the project are then determined and divided by eight to set the design time in terms of days. For example, if a civil engineering project has an estimated cost of \$100,000, and the related degree of difficulty of three is input by the user, the system would use the rule illustrated in Figure 4.

⁹Lexington Blue Grass (LBG) Form 5, "Project Prioritization."

Rule #4:

If: [TYPE] = "CIVIL"
and [TECH] = 3

Then: [DCOST] is given the value 0.03
and [CTIME] is given the value $(([EST] * [DCOST]/[CRATE]) * 1.3)/8$

where
TYPE = engineering discipline
TECH = degree of design difficulty
DCOST = percentage of total estimate charged to design
CTIME = time for civil engineer to complete design
CRATE = civil engineer's hourly rate
EST = total project estimate .

Figure 4. Knowledge-based rule to determine project design duration.

This particular project would take 17.4 days to design, using an hourly rate of \$28/hr. Similar rules are used for each discipline. The varying parameter in the rules, along with TYPE of project, is the value of DCOST. The DCOST values range from 0.03 to 0.06 depending on the project's design degree of difficulty. The degree of difficulty at this point is user dependent; however, future research may enable the system to make the determination based on historical data. Table 8 shows the DCOST values related to the degree of difficulty.

The system can help to determine other management factors. If the project selection shows that construction season is relevant, Rule 1 affixes the note to the design schedule that the "CONSTRUCTION SEASON SHOULD BE CONSIDERED."

The system can also recommend whether the project should be done in-house or contracted to an A/E firm. If the design time is greater than 1 year, the system concludes that the project should be contracted to an outside firm. Depending on the installation, and the number and experience of the personnel, the period of 1 year may need to be revised to some lower limit, such as 30 days.

If the project estimate is less than \$2500, the system concludes that the project requires no design and adds the comment "PROBABLE WORKSHOP PROJECT." Finally, if the project has been given a command priority of eight or nine, it is determined to be a possible backlog project.

Table 8
DCOST Related to Degree of Difficulty

Degree of Difficulty	DCOST
1 - 4	0.03
5 & 6	0.04
7 & 8	0.05
9	0.06

The data produced by the expert system is then written to a file that stores the following information for each project:

- type
- title
- location
- status
- estimate
- priority
- construction season considerations
- date entered into system
- time needed to design project.

The data is then stored in one of four separate data files, dependent on the project type, and is indexed by priority. Once this is done for each discipline, a dBASE program accumulates the time needed for all design projects. The user then has the option to print a project design schedule for the current fiscal year. The schedules are produced for each engineering discipline within the FE's organization.

Figure 5 shows a typical schedule produced for installation civil engineers. The schedule lists six projects, the workshop projects first, and the remaining projects by decreasing priority. The third project listed is a suggested A/E project, for which the system does not consider in-house design time. All suggested A/E projects have the same design completion date, contingent on timing needs. The last project has a low priority; the system suggests backlogging this project. A backlog may occur when the accumulated design times exceed available manhours. The schedule also sums the total project cost estimates.

CIVIL ENGINEERING DESIGN SCHEDULE FOR FISCAL YEAR 88

PROJ#	PROJECT TITLE	LOC/BLDG	PROJ EST DATE	DESIGN STATUS	LAST UPDATE	COMMENTS
				COMP		
05-88	PLACEMENT OF HANDICAPPED RAMP	1	1300	00-00 PRE-DESIGN	10/23/87	PROBABLE WORKSHOP PROJECT
06-88	NEW AMMO STORAGE IGLOO	SEC-3	100000	11-09 DESIGN	10/23/87	CONSIDER CONSTRUCTION SEASON
06-88	NEW SEWAGE PLANT	SEC-4	100000000	11-09 DESIGN	10/23/87	SUGGESTED A/E PROJECT
01-88	REPAIR ROAD WAY	NEW RD.	50000	11-18 DESIGN	10/23/87	CONSIDER CONSTRUCTION SEASON
03-88	REPLACE ROOFING SYSTEM	15	70000	12-14 DESIGN	10/23/87	CONSIDER CONSTRUCTION SEASON
02-88	SEWER SYS	SEC-2	35000	12-21 DESIGN	10/23/87	
07-88	REMOVE WALL INTERIOR	4	6000	12-23 DESIGN	10/23/87	POSSIBLE BACKLOG PROJECT

Figure 5. Sample design project schedule.

Prototype Evaluation

The primary purpose of the DPS Advisor was to determine the feasibility of scheduling projects by an expert system. In fact, an expert system can help to schedule design projects by predetermined priorities. However, accumulating the data required to establish these priorities to make useful recommendations can be problematic.

The installation's command priority is primary data in determining the project design schedule. Often the commander of an installation bases priorities on user input and local priorities. Such subjective information is inconsistent with expert system use. The priority system established at Lexington Bluegrass Army Depot helps to implement a consistent set of priorities, but integrates relatively simple knowledge which can already be processed by a traditional computer-based system.

Data pertaining to the engineering aspects of each project, such as the degree of difficulty to design, construction season considerations, and cost are very difficult to codify into a knowledge base because the degree of difficulty in designing a project is a factor to be determined by qualified engineers, who often disagree on this subjective value. Any value that relies on expert input is, by definition, nonautomated. To automate the process, additional information must be gathered, by interviewing experts from each engineering discipline and by analyzing past design procedures. This would lead to the creation of a database containing project descriptions, along with a design degree of difficulty for all completed projects at a particular installation. When the user enters a new project description, the system could search the database, match the new project with an existing project, and determine a degree of difficulty for the new project. While this is a feasible solution, it still relies substantially on the variable quantity of expert opinion.

Construction season consideration and cost estimating could also be determined by similar expert system processes. However, seasonal considerations are really based on common sense and do not require expert input or the use of an expert system. Cost estimating has already been automated by such Army-wide systems as the U.S. Army Corps of Engineers' Facility Engineering Job Estimating System [FEJE], which needs no duplication.

5 CONCLUSIONS AND RECOMMENDATIONS

This study concludes that the development of an expert system is a feasible and justifiable means to improve present methods for prioritizing RPMA projects.

This study also concludes that the development of an expert system to perform design scheduling is not entirely worthwhile. However, certain system capabilities described in this report, while not requiring implementation of an expert system, could prove useful to Engineering Plans and Services personnel. Dynamic schedule generation that considers changes in priorities, manpower, funding, and seasonal considerations could still be a useful tool.

It is recommended that investigation continue in the development of an expert system for project prioritization, to be used as a training tool for new personnel and as an "intelligent" Standard Operating Procedure to improve consistency in deciding priorities.

It is recommended that knowledge-based programming techniques be combined with database and schedule-generating capabilities to serve as an intelligent control structure for a traditional automated scheduling system.

The key to developing an expert system lies in identifying and defining the problem to be solved, and in locating the expert knowledge which applies to that problem. It is further recommended that the Army sponsor the formulation of an RPMA Expert Systems Group, consisting of experts in the development of expert systems and in the RPMA decisionmaking process. It is also recommended that this group conduct Army-wide workshops to determine expert system applications that would be most beneficial to the Army.

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CERD-L

US Army Engineer Districts
ATTN: Library (41)

US Army Engr Divisions
ATTN: Library (14)

US Army Europe
V Corps
ATTN: DEH (11)
VII Corps
ATTN: DEH (16)
USASSETAF
ATTN: AESE-EN-D 09019

FORSCOM (28)
FORSCOM Engineer, ATTN: Spt Det 15071
ATTN: DEH

HSC
Ft. Sam Houston AMC 78234
ATTN: HSLO-F 170
Fitzsimons AMC 80045 7/90
ATTN: HSHG-DEH
Walter Reed AMC 20307
ATTN: Facilities Engineer

INSCOM - Ch, Instl. Div.
Arlington Hall Station 22212
ATTN: Engr & Hsg Div
Vin: Hill Farms Station 22186
ATTN: LAV-DEH
Ft. Belvoir 22060
ATTN: Facilities Engineer (3)

USA AMCCOM 61299
ATTN: AMSMC-RI
ATTN: AMSMC-IS

Military Dist of Washington
ATTN: DEH
Cameron Station (3) 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

TRADOC (19)
HQ, TRADOC, ATTN: ATEN-DEH 23651
ATTN: DEH

USAIS
Fort Huachuca 85613
ATTN: Facilities Engineer (3)
Fort Ritchie 21719

WESTCOM
Fort Shafter 96858
ATTN: DEH
ATTN: APEN-A

Fort Belvoir, VA
ATTN: Australian Liaison Officer 22060
ATTN: Water Resource Center 22060
ATTN: Engr Studies Center 22060
ATTN: Engr Topographic Lab 22060
ATTN: ATZA-TE-SW 22060
ATTN: CECC-R 22060

CECRL, ATTN: Library 03755

CEWES, ATTN: Library 39180

Engineering Societies Library
New York, NY 10017

National Guard Bureau 20310
Installation Division

US Government Printing Office 20401
Receiving/Depository Section (2)

Defense Technical Ino. Center 22304
ATTN: DTIC FAB (2)